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ORIGIN OF THE GULF STREAM AND CIRCULATION OF WATERS IN THE GULF OF MEXICO, WITH SPECIAL REFERENCE TO THE EFFECT ON JETTY CONSTRUCTION.

By N. B. SWEITZER, Jr., Jun. Am. Soc. C. E.

PRESENTED JUNE 15TH, 1898.

WITH DISCUSSION.

The origin of the Gulf Stream and the circulation in the Gulf of Mexico have never been satisfactorily settled. Many theories have been advanced from time to time, but none as yet have been established upon acceptable proof. The commonly received theory of the present day, that these currents flow in from the South Atlantic, pass the north shore of Yucatan, follow the coast line of Mexico and Texas in a north-northeasterly direction, and finally escape through the Straits of Florida, appears to be plainly contradicted by evidence gathered from the various surveys of the past, together with recent discoveries in connection with the several deep-water projects along the coast of Texas.

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The true solution of the question seems to be that the currents coming in through the Straits of Yucatan follow one of two courses,

dependent upon the variations of barometric and planetary conditions, viz.:

(1) During the high declination of the moon, coincident with a continued low barometer off Cape Hatteras and a high barometer in the Gulf of Mexico, they flow from the Yucatan Channel in a northeasterly direction around the extreme west coast of Cuba and pass out into the Atlantic through the Straits of Florida, where they become known as the Gulf Stream.

(2) Under opposite atmospheric conditions, and during the low declination of the moon, the Channel of Yucatan pours its waters into the Gulf, so that they spread out in all directions, moving on its center; thence, being deflected by the outward flow of contrary currents, they also pass through the Straits of Florida as the Gulf Stream.

In order to understand these currents aright, especially those in the western part of the Gulf, it will be necessary to review, as briefly as possible, past observations and discoveries concerning the Gulf Stream and equatorial currents. The discovery of America may be said to be due primarily to the Gulf Stream. Long before the time of Columbus, there had been noticed in the débris constantly washed upon the shores of Scotland, Norway and France, pieces of carved wood, and canoes of curious design, quite foreign to the people of the known world. Little was needed, therefore, to convince a reflective mind, like that of the great explorer, that these things came from lands beyond the seas, which could be reached by sailing westward.

As far as known, Columbus was the first navigator to observe the oceanic currents; having noticed, when sounding in the Sargasso Sea, that the lead appeared to recede from the ship, which he rightly interpreted as meaning that the ship drifted away from the lead. Speaking of the strong currents which, on his later voyages, he noticed in the Caribbean Sea, as also among the Antilles and off the coast of Honduras, he says:

"When I left the Dragon's Mouth I found the sea ran so strongly to the westward that between the hour of Mass, when I weighed anchor, and the hour of Complines, I made sixty-five leagues of 4 miles each with gentle winds." He further adds: "I hold it for certain that the waters of the sea move from east to west, with the sky, and that in passing this track they hold a more rapid course and have thus carried away larger tracks of land, and that from hence have resulted the great number of islands."

It was about this time that Sebastian Cabot noted the Labrador current. However, the first authentic mention of the Gulf Stream is found in the log of Antonio De Alaminos, the pilot of Ponce de Leon in his famous expedition for the Fountain of Life in 1513. Having set out from Porto Rico he crossed the stream in the neighborhood of Cape Canaveral, and, after reaching latitude 30° north, he turned and coasted as far as Tortugas, stemming the current for several hundred miles. The log says that they met currents which they were unable to stem even when they had good winds; and though they appeared to be going through the water at a high rate of speed they recognized that they were really drifting backward, and that the stream was stronger than the wind. It states further that when these vessels came to anchor near the coast, one of them, a brig, being in water too deep to anchor, was soon carried out of sight by the stream.

This knowledge subsequently proved of great value to Alaminos when Cortez, in his expedition for the conquest of Mexico, placed him in command of the entire fleet. Later, when it became necessary for Cortez to send envoys to Spain to save his life, he gave Alaminos the speediest vessel of the fleet, with the instructions to sail to the north of Cuba and into the Atlantic through the Florida Straits, thus utilizing the Gulf Stream. This route subsequently became the chief course of navigation between the West Indies and Europe, and played an important part in the later development of the City of Havana.

Sir Humphrey Gilbert in some of his writings seeks to trace the motion of the waters from the African coast to America, and writes:

"The current runs all along the eastern coast of that country northward as far as Cape Freddo, being the farthest known place of the same continent towards the north," from which he concludes that "it must either flow around the north of America into the South Sea, or it must needs strike over upon the coast of Iceland, Norway and Finland."

He accepted the former theory because he was anxious to prove the existence of the northwest passage.

One of the earliest theories advanced to account for the Gulf Stream appears in "La Cosmographie," in which it is claimed that the currents in the Straits of Florida are caused by the rivers emptying into the Gulf of Mexico. John White, Governor of Roanoke, referring to a voyage from Florida Keys to Virginia about 1590, says:

"We lost sight of the coast and stood to sea for to gain the help of the currents, which runneth much swifter farre off than in sight of the coast, for from the Cape of Florida all along the shore are none but eddie currents setting to the south and southwest."

Thus it may be seen that at this early date the existence of a swift, powerful current was known; that it extended from Florida Keys, "out of sight of the coast," northward beyond Virginia; and, that between this current and the coast were "eddie currents setting to the south and southwest." In other words, the axis of the Gulf Stream had been located and the contrary current flowing southward adjacent to the coast noted.

Isaac Vassius writes, about the year 1663:

"With the general equatorial current the waters run towards Brazil along Guyana and enter the Gulf of Mexico, and from thence turning obliquely, they pass rapidly through the Straits of Bahama. On the one side they bathe the coast of Florida and Virginia and the entire shore of North America, and on the other they run directly east until they reach opposite shores of Europe and Africa."

Here it is seen that the writer notices the entrance of the currents into the Gulf of Mexico, from the direction of the Guyana coast, through the Caribbean Sea, coming into the Gulf between Cuba and Yucatan.

On their entrance into the Gulf he points out that they increase in rapidity, "turning obliquely" towards the Straits of Florida or Bahama. Strange as it may seem, these observations of Vassius, made as long ago as 1663, are much nearer the truth than those of writers as late even as to-day.

It is interesting to compare this information with the article in the "Encyclopædia Britannica" on the Atlantic Ocean (see Fig. 1). Here it is stated that the current

"passes westwards along the northern coast of South America until it is deflected northwards by the coast line of Central America, and is driven between the peninsula of Yucatan and the western extremity of Cuba into the Gulf of Mexico, at the rate of from 30 to 60 miles per day. A portion of it passes direct to the northeast along the northern shore of Cuba; but by far the larger part sweeps round the Gulf, following the course of its coast line, and approaches the coast of Cuba from the northwest as a broad deep stream of no great velocity, seldom running more than 30 miles per day."

In the light of recent investigation, the theory of Vassius appears to have been more nearly right. From the time of Vassius very little

notice seems to have been taken of the Gulf Stream until about the year 1770 when some American whalers, sailing from the Bahama banks, southeast to the Azores and north to Baffin's Bay, made the discovery that the whales stayed north or south of a certain line which afterward proved to be the Gulf Stream.

This knowledge was communicated to American navigators who found it of great value in their voyages to Europe. About this time Benjamin Franklin took up the matter and published a map which was rejected by the British Government and the English ship captains, who, true to the inherited conservatism of their nature, continued their old course, often arriving at New York when American vessels, which had left England at the same time, were half way across the Atlantic on their return voyage. Upon the outbreak of the war with England, Dr. Franklin suppressed this map, but the knowledge gained from the experience of the whalers proved to be of the greatest possible advantage to the infant navy of the American Colonies.

FIG. 1.

Dr. Franklin now made a number of voyages across the Atlantic, and from this time dates the first truly systematic and scientific investigation of the Gulf Stream. After noting several observations of the temperature made with the aid of the thermometer, Franklin says:

"I find that it (the Gulf Stream) is always warmer than the sea on each side of it, and it will appear from thence that the thermometer may be a useful instrument to the navigator; since currents coming from the northern into the southern seas will probably be found colder than the water of those seas, as the currents from the southern seas are apt to be warmer."

A. von Humboldt next published a remarkable work on the Gulf Stream, in which he maintained that it was not the same at all seasons, but depended to a great extent upon the wind. This is found to be true, at least as far as velocity is concerned.

The excerpt on page 91 is taken from an exhaustive report by Lieutenant Pillsbury, U. S. N.:

"During the first quarter of this century the British Admiralty office had collected a great quantity of material on the subject of ocean currents and meteorology, most of which had never been known to the public. Mr. James Rennell, who had devoted his life to the subject of geography and particularly to ocean currents, was given the task of compiling and collecting data. He combined the results on large charts of the ocean, which were the admiration of the day. He also wrote a volume entitled, 'An Investigation of the Subjects of the Currents in the Atlantic Ocean.'

"Major Rennell adopted Dr. Franklin's theory as to the principal cause of ocean currents, and divided them into two classes, drift currents, caused by constant or long-continued winds on the surface of the water, and stream currents which are formed by the accumulation of water by the drift currents meeting an obstacle and thrown sideways or out of its usual course. The Gulf Steam he placed in the latter class. He considered the water in the North Atlantic a drift current impelled by the prevailing westerly winds, and these also were the cause of the African current."

From these and other observations Major Rennell draws the following conclusions:

(1) "That there existed a change in the position of the column of warm water from time to time"; (2) "that the breadth varies at times in the proportion of more than two to one"; (3) "that these changes had been observed sometimes to be very sudden, *e. g.*, on one occasion the stream had been found to be 140 miles in width, and in two weeks later at the same spot it was 320 miles;" (4) "that these changes did not follow any regular course of the seasons, for it was 320 miles wide in May, 1820, and only 186 miles in May, 1821, nearly at the same place;" (5) "that on the northern side of the stream the body of warm water is more permanent than on the south, and that the warmest water is found to the north, as if indicating the strongest part of the stream there;" (6) "that the existence of warm water does not necessarily indicate the presence of the stream, but must be regarded as an overflow or deposit of superabundant water; or even from a counter current;" (7) "that there are without doubt veins of colder water within the body of warm currents."

These deductions of Major Rennell were a vast advance upon anything that had previously been attempted. True, some of them are faulty, but it must be remembered that the temperature observations were those of the surface, and that surface-water, impelled by a gale of wind, will traverse many hundreds of miles in a short space of time. Besides this, his conclusions were gathered from totally unconnected data, such as reports of merchantmen, naval officers, and ship captains

of all classes, whose observations, especially for longitude, were often careless in method and detail. A period of about twenty years elapsed before anything further was accomplished in the exploration of the Gulf Stream. Then, in the year 1844, Professor A. W. Bache, of the United States Coast Survey, began the first really scientific and comprehensive survey of this great ocean river.

Origin of Ocean Currents.—It will be necessary to notice some of the more important theories advanced. Columbus held the opinion that the waters followed the motions of the heavens about the earth, in which view Sir Humphrey Gilbert concurred. Kepler believed the flow of the currents to be considerably influenced by the motion of the earth; the cohesion of the particles of water being less than that of land, the water was naturally left behind in the revolution of the earth on its axis.

The scientific world at that time was considerably agitated by the opposing theories of Passine and Furnier. The former held that the currents were caused by the heat of the sun attracting the ocean, forming an immense mountain of water, which vessels had great difficulty in ascending. He thought that this mountain moved constantly westward until it met the South American coast, which turned it and caused it to move northwestward. Furnier, on the contrary, claimed that the sun caused an immense hole to be made by evaporation into which the waters rushed, thus causing the currents. Like the fable of the two knights on opposite sides of the statue, they were both right to a certain extent.

Kircher, a learned mathematician of Würzburg, attributed the currents to the effect of the winds, which, when deflected by the shore line, formed currents now designated as stream currents. He also noticed the influence of the moon on these currents.

Dr. Franklin strongly advocated the theory that the constant winds blowing toward South America caused a rising in the level of the water, which, being deflected mostly northward, entered the "Bay of Mexico," flowing north of Cuba, and from thence to the Banks of Newfoundland. Von Humboldt attributed the Gulf Stream to the winds, the melting of ice in the polar regions, and the revolution of the earth on its axis.

Lieutenant Maury, U. S. N., in his valuable work entitled "Physical Geography of the Sea," says that the ocean currents are due to

various causes, the more important of which are: *first*, the difference in the specific gravity of sea water in the tropics and in the polar regions; *second*, the influence of the winds. He says:

"Difference of specific gravity is the *chief* cause. Whenever the waters in one part of the sea differ in specific gravity from the waters in another part, no matter from what cause the difference may arise, or how great may be the distance between two such parts of the sea, the heavier water will flow (by the shortest route) towards the lighter; and the lighter in its turn will seek the place from whence the heavier came."

"In other words, from whatever part of the sea a current flows, back to that part a current of equal volume must flow."

He then introduces two qualifying theories to explain the western flow of the equatorial current, viz., the rotation of the earth and the winds. There is no doubt that the evaporation in mid-Atlantic, in the latitude of Cape St. Roque, between the continents of Africa and South America, far exceeds the precipitation, and consequently the specific gravity there must be greater than that of either the Arctic or Antarctic Oceans, which are little more than brackish.

If, therefore, Lieut. Maury is correct in his supposition, that the difference of specific gravity is the chief cause of oceanic circulation, then there would necessarily be a flow of the heavier saline waters from the equator direct to the south and north, and a consequent return of the lighter and fresher waters from the polar regions.

Such, however, is not the case, and to account for the flow of ocean currents another cause than that of specific gravity must be sought. This cause will be found in the winds which blow constantly from Africa to South America and the West Indies. The equatorial current moves directly west, unaffected by its specific gravity. The rotation of the earth doubtless does affect the ocean currents, but its effect is far less than that of the winds. Specific gravity too may be a considerable aid to oceanic circulation, but it is a mistake to suppose it to be the prime cause. Difference of barometric pressure, especially in shallow bays and gulfs, perceptibly affects the currents by accelerating or retarding their velocity. The effect of this force is seen to be very great when it is remembered that a difference of 1 in. in the barometer will be accompanied by a difference in the elevation of the Gulf of more than a foot. Taking into consideration the vast quantity of water involved in such elevation, one can realize something of the tremendous volume which pours into the Atlantic.

Circulation in the Gulf of Mexico.—Having reviewed the history of the Gulf Stream investigation and the more important of the theories advanced to account for its origin, the original question, concerning the course followed by the currents between the time of their entrance into the Gulf of Mexico at Yucatan, and their departure through the Straits of Florida, will be considered.

The question has never been regarded as satisfactorily answered, and it is a remarkable fact that even eminent authorities like Maury and Pillsbury seem to evade it. Maury says :

"It (the current) enters the Caribbean Sea and the Gulf of Mexico, from whence it issues through the Straits of Florida as the well-known Gulf Stream."

Lieutenant Pillsbury says in his report, page 591 :

"We have thus followed the water driven by the *vis a tergo* of the trade winds from the coast of Africa to the Yucatan Channel, from which it flows into the Gulf of Mexico and through the Straits of Florida into the Atlantic."

Reference has already been made to the popular opinion, as expressed in the "Encyclopædia Britannica," viz., that the waters come in through the Yucatan Channel and follow the coast line of Mexico and Texas, finally departing through the Florida Straits; but a more reasonable suggestion is found in the report of the Superintendent of the United States Coast Survey published in 1895, in which he states that the waters of the Gulf of Mexico are "erratic in direction, and feeble in force," and suggests what appears to be the correct theory, that the directions of the currents entering and leaving the Gulf are dependent upon the declination of the moon and certain conditions of barometric pressure.

The winds can have but little influence over the waters in passing through these channels, as they are deep-streamed currents, flowing at a probable depth of from 1 000 to 1 500 fathoms; but the circulation in the Gulf is unmistakably dependent to a large extent upon the winds.

It was once thought by many that the Mississippi River was the "fountain-head of the Gulf Stream" and caused a circular motion in the Gulf by flowing direct from its mouth to the Straits of Florida. The absurdity of this idea is readily seen from the fact that the amount of water emptied into the Gulf by this river is only 0.36 cubic mile per twenty-four hours,* while the amount received through the

* Humphreys and Abbot.

Yucatan Channel is 652 cubic miles in the same length of time. This fancy is still further disposed of by the discovery that the current of the Mississippi enters the western part of the Gulf and flows in a southwesterly direction.

Here is a good illustration of the opportunity afforded of tracing a stream of fresh water into the sea by means of the difference of density; for by this means the waters of the Mississippi are easily traceable from its mouth in a southwesterly direction, to a point only a little south of the latitude of the Rio Grande, and not far east of the longitude of Galveston.

The specific gravity theory will now be considered. The specific gravity map of the Gulf* shows that the line of maximum density extends from about 300 miles north of Yucatan nearly west to the eastern shores of Mexico. The northern half of the Gulf is quite light, except off the western coast of Florida. If, then, this specific gravity theory be the right one, there will be a flow from the east, southeast and south toward the north and northwest. This, to a certain extent, is true, especially where the motion of the waters is accelerated by the prevailing winds which produce drift currents along the northern and western shores of the Gulf. For nearly ten months in the year these winds blow constantly from the south to a little north of east and for at least nine months they seldom ever change from the southeast. During these months it is not only constant, but strong, and causes the waters to move toward the northwest. When they reach the northern part of the Gulf they are deflected by the shore line, and move westward. On the other hand, the waters from the southwestern part impinge on the coast of Mexico, and produce the current which flows north along the shores of Mexico and Texas.

These two currents meet in the western part of the Gulf, raising the surface and thereby producing a return current which passes south and eastward toward the Straits of Florida. The current along the coast of Mexico is feeble in force near its starting point, off the west of the Yucatan peninsula, but gradually increases until it reaches its maximum velocity between Tampico and the Rio Grande, where it flows at the rate of 3 miles an hour, and then continues to diminish until it meets the contrary current from the east.

The circulation of the waters in the Gulf is shown in Fig. 2.

* Report of the United States Coast Survey for 1895, p. 369.

A considerable agitation of the waters, covering an area of about 100 square miles, occurs off the west coast of Texas, about 40 miles south and 20 miles east of Aransas Pass, which can only be accounted for as resulting from the meeting of two opposing currents. In the immediate neighborhood of this phenomenon the coast is covered with débris of every description, among which the fir tree of Wisconsin, the palmetto of Florida, the cocoanut and other products peculiar to the tropical regions of the South are found lying side by side.

The chief obstacle to harbor improvements along the coast of Texas is the vast quantity of sand which, being stirred up and held in suspension by the waves, is carried by the currents and deposited in the channels of harbors. A current, to carry heavy sands, must have a bottom velocity of about 2 ft. per second, thus necessitating a much greater surface velocity, which it is known these currents do not have, of themselves, under ordinary circumstances, as they rarely move faster than 2½ miles per hour. Therefore, it is concluded that the wave action must be the chief factor in the dislodgement of the sands, and, in connection with the littoral currents, determines the position and form of harbor jetties.

FIG. 2.

The author's attention was first attracted to the littoral currents by the construction of a north jetty at Aransas Pass, Texas, in 1895. Prior to that time attempts had been made to obtain deep water by the construction of jetties on the south side of the channel, but they failed through the lack of capital required for their completion.

In that year the Aransas Harbor Company built a jetty in the form of a letter S, on the north side of the channel, running east and west half a mile from the southeast extremity of St. Joseph Island. This work was conducted upon the supposition that the littoral current came from the north, and that it would be so deflected by the jetty as to enter Aransas Bay between the western end of the jetty and St.

Joseph Island. It was further imagined that during ebb tide this current would meet the outgoing current in the Pass, thus neutralizing both velocities and preventing the outward flow from passing north of the jetty; or, if the ebb current was the stronger, they would pass out through the channel on the south side of the jetty.

Long before this work was completed the author became satisfied that the littoral current came from the south, as, by a series of experiments, he had previously proved to be the case at Pass Cavallo, not far north of Aransas Pass, where the conditions were the same.

When the jetty was completed it was found that there was less water in the channel than before the work began. Colonel Goodyear, the last contractor, recognized the mistake that had been made, and proceeded to finish the jetty on the south side of the Pass, thus excluding the drift sand brought in by the currents and waves from the south, with the gratifying result that the author's latest survey, made in June, 1897, showed a marked increase in the depth of the channel. Further evidence is unnecessary to establish the fact that, at this point, at least, the littoral currents flow from the south.

If the jetty construction upon the coasts of Texas and Mexico is examined, it will be found that these currents maintain a uniformly northern course from Tampico to Galveston, where they meet those coming from the westward from the mouth of the Mississippi.

At Tampico the south jetty was built first in order to protect the channel from southern sand-bearing currents. At Brazos, Santiago, Texas, the same thing was done. Lieutenant G. A. Zimm,* writes:

"The direction of the channel across the bar depends upon the direction of the winds and littoral currents. During nine months of the year southerly winds blow and there is a littoral current from the south."

The same thing is noticed on the sketch accompanying Captain McClellan's report on this harbor in 1853. At Pass Cabal only one jetty was built, and that was also placed on the south side. A jetty was commenced at the mouth of the Brazos River on the north side, but Major Ernst, in his report of September 6th, 1887, remarks:

"The map of recent survey shows the channel, instead of running southeast in the direction intended, turned off at a right angle and running northeast across the jetty."

* Annual Report of Chief of Engineers, U. S. A., page 1330.

At Galveston the South Jetty was built first. At passes east of Galveston, however, the jetties are almost invariably constructed on the east side, to check the sand-bearing currents in their westward flow. Among these may be mentioned Calcasieu River Pass, La.;* also Sabine River Pass.†

It is well known that at the mouth of the Mississippi the littoral currents flow from the east. Hence, it may be concluded that the currents flowing westward are on the northern shore of the Gulf, and those flowing north along the western shore meet at some point near Galveston, the location of which is variable, as it is dependent upon the direction and force of the winds.

Summing up these observations of the Gulf currents, it is found that there is abundant evidence of the presence of two sets of currents in the Gulf of Mexico, viz., deep-stream currents and littoral-drift currents.

The former enter the Gulf through the Yucatan Channel, and, under certain barometric and planetary conditions, pass by the western extremity of Cuba and flow out through the Straits of Florida, or else, under converse planetary and atmospheric conditions, they spread out over the Gulf in all directions, moving on its center.

The littoral-drift currents are originated through the agency of the prevailing southeast winds and flow northward along the western boundary of the Gulf, and west along the northern boundary, meeting in the vicinity of Galveston and forming a stream-current which flows in a southeasterly direction toward the Straits of Florida.

In the past there has been far too little attention paid to the motion of the Gulf waters. Were they better understood, there can be no doubt that vast sums of public and private capital might have been expended more judiciously than they have been, resulting in more real and lasting good to the people of the coast country. If, therefore, this paper is the means of inducing a greater interest in these Gulf currents, which have such a direct and important bearing on trade and commerce, the author will feel that it has successfully accomplished its mission.

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* Report of Major W. H. Heuer, 1886.

† Report of Secretary of War for 1895.

DISCUSSION.

L. M. HAUPT, M. Am. Soc. C. E.—The title of the paper is broad, and the research shown in presenting the subject is commendable. It is true that the engineer should ascertain the remote as well as the immediate causes operating to produce certain observed effects, in order that he may properly apply them to the wants of man. Mr. Haupt.

It is also true that unless a correct diagnosis is made of the effects and their causes, one may readily fall into errors in reaching conclusions, and *errare est humanum*.

Turning first to the general theory advanced by the author, it becomes necessary to refer to the physical features of the gulf littoral to interpret his description correctly.

The author, in the opening of his paper, contravenes the "commonly received theory," that the currents "flowing in from the South Atlantic pass the north shore of Yucatan, follow the coast line of Mexico and Texas in a northwesterly direction, and finally escape through the Straits of Florida."

In his subsequent exposition of his own theory the author admits the correctness of the direction of ingress and egress, leaving in dispute the disposition of the currents in the basin of the Gulf when he says that under certain conditions they flow (1) northeasterly around the west coast of Cuba and pass off directly into the Straits, or (2) under opposite conditions "they spread out in all directions, moving on its center; thence, being deflected by the outward flow of contrary currents, they also pass through the Straits of Florida as the Gulf Stream."

This leaves the matter in rather a chaotic condition as to the origin of the counter deflecting currents and the direction of the resultant littoral movements.

Passing the history of the origin of the Gulf Stream, and turning to page 95, the author states with reference to the specific gravity theory: "If, then, this specific gravity theory be the right one, there will be a flow from the east, southeast and south toward the north and northwest. This to a certain extent is true, especially where the motion of the waters is accelerated by the prevailing winds," which are said to prevail for nine months in the year. "They seldom ever change from the southeast. During these months, it is not only constant, but strong, and causes the waters to move toward the northwest." This leaves us in a quandary. If that is the resultant direction and flow for nine months of the year, the question naturally arises as to the disposition of all this water, and why is Texas not inundated? But this is explained as follows: "When they reach the northern part of the Gulf they are deflected by the shore line, and move westward. On the other hand, the waters from the southwestern part impinge on the

Mr. Haupt. coast of Mexico, and produce a current which flows north along the coast of Mexico and Texas." That is on the portion of the coast south of Tampico. These two currents, as he explains, meet in the western part of the Gulf, raising the surface, and produce a return current, passing south and east toward the coast of Florida. Consequently there must be two conflicting currents moving in nearly opposite directions, one of them nine months in the year, and the other effecting its escape across the path of the first in some unexplained manner. No attention is paid apparently to the vertical movement of the currents, which is a very important factor in all these studies. As an illustration of that, attention is directed to the Narrows in New York Bay, where the maximum movement is apparently outward; whereas, the inward or flood movement prevails in the bottom of that gorge for eleven hours out of the twelve. There is a vertical eddy at that point, and material deposited in the Lower Bay is carried to the Upper.

FIG. 3.

The author continues: "The current along the coast of Mexico is feeble in force near its starting point, off the west of the Yucatan peninsula, but gradually increases until it reaches its maximum velocity between Tampico and the Rio Grande, where it flows at the rate of 3 miles an hour." But what becomes of it? The diagram (Fig. 2) shows it to be reflected toward the center of the Gulf, where it is met by the entering currents off Yucatan.

These were some of the thoughts suggested by a perusal of the paper. They leave the matter in an unsatisfactory condition, but it

is an important as well as an interesting question from a theoretic and scientific standpoint. Mr. Haupt.

It may be *àpropos* to suggest a theory of circulation which may fit the case. Let it be assumed that the impelling stream enters the Gulf as a rack would enter between two gears or pinions. As it comes in, the currents are dispersed to the right and left into these lateral basins, where, being diverted by the configuration of the coast, eddies will be formed of greater or lesser magnitude, the one to the right, the other to the left, while the movement of the water in the isolated or protected bay west of Yucatan will take up a reverse direction, so that the currents from this overflow, one hugging the northwest shore, the other the southwest, will form a resultant uniting again with the main stream, and this action seems to conform very closely to the observed results. In other words, under this theory, there should be three large eddies in the Gulf which indicate the direction of the flow of the currents as shown by the letters *A B C D — E G D — A H I J — A B′ K* (Fig. 3).

Coming to the practical applications, which, of course, are the more important factors for engineers, a map published in the reports of the Chief of Engineers shows the peculiar feature, that at all of these Texas entrances, the discharge through the ebb channel or the main ship channel lies in the direction of the meridian, that is, nearly due north and south. This is very suggestive because it shows that as the western bight of the bay is approached, the channel is found to lie nearer the western shore. The position of the channel with reference to the inlet is an important characteristic. It is fully discussed in the paper on "Physical Phenomena of Harbor Entrances."* In a case of that kind the indications would be that it is the resultant of a littoral movement, taking the seasons through for the entire year, and the ebb currents would be flexed to the south, while the bar crossing would be at the point of least resistance. That being the case it furnishes the key to the solution of these harbor problems, and the development recently made, or proposed to be made, in this science is to create the depths by the single jetty instead of two, as formerly.

The continental practice has been to attempt to utilize the ebb currents by concentration between two jetties, so that the currents may scour out between them, but it has not been found satisfactory in the long experience of maritime engineers. It invariably happens that wherever two jetties of that kind are built, they have to be extended as the groins connecting them with the shore fill with sand.

A more recent examination, made August 2d, by H. C. Ripley, M. Am. Soc. C. E., and the writer, at a season when the southeast winds tend to build up the bar, showed a remarkable deepening and a progressive and rapid improvement in the channel, there being over 18 ft.

* *Proceedings*, American Philosophical Society, 1888.

Mr. Haupt

at points where there were formerly but 8 ft. The pilots report deeper water on the bar than they have ever known to exist.

These facts would seem to refute the statement of the author that a mistake had been made and that the results of the work were injurious.

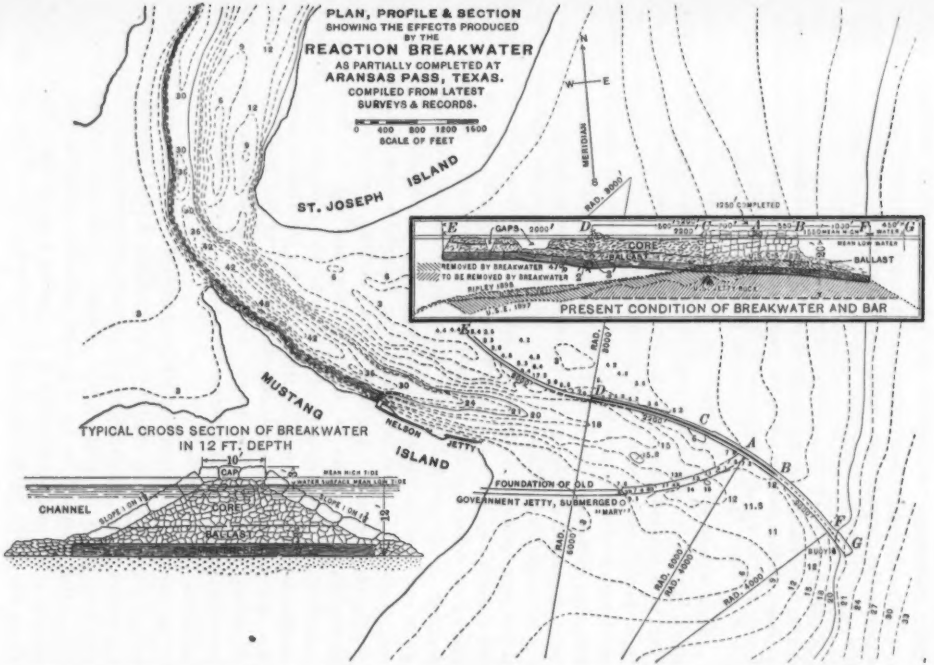
There are a few points in the paper which the speaker is unable to reconcile with the well-known and accepted phenomena at the Gulf inlets, and which are fully confirmed by the Reports of the United States Engineers and the comparisons of the Coast Survey charts. This confusion may arise from a failure to make a clear distinction between the off-shore and littoral currents, which would seem to have resultant motions in opposite directions; but, however this may be, it is generally assumed that the motion of a body is in the direction of the resultant of the component forces acting upon it. This being a physical law, the direction of movement of the inlets (when unrestricted) should indicate the direction of the forces causing that effect. Hence, when it is found that an inlet is moving to the south, it is difficult to understand how the littoral currents (producing that progression) flow from the south. For example, the case cited, Aransas Pass, has unquestionably moved over a mile, in 25 years, to the south, the average rate being stated as 260 ft. per annum. This being a fact, it is difficult to understand how the impelling force can flow from the south.

The author makes several statements as to the *S*-shaped jetty, which, he remarks, was built "on the supposition that the littoral current came from the north," etc. As the originator of this design and one of the consulting engineers, who has been kept well informed as to progress and results, the speaker regrets to have to take exception to the accuracy of the statements which his colleague has thus publicly made, and desires to make the necessary corrections, *seriatim*.

The author states:

"Long before this work was completed the author became satisfied that the littoral current came from the south, as * * * at Pass Cavallo, * * * where the conditions were the same."

As this work is still far from being completed, it would seem unjust to deduce conclusions therefrom, inasmuch as the breakwater was not designed to change the direction of the littoral drift, from north to south, and has not done so, but to utilize its agencies; first, to arrest the sand and defend the channel from its encroachments; while, secondly, it applied the changed conditions of equilibrium, which it created in the currents, to cause a rapid erosion at ebb, by reaction, across the crest of the bar. So remarkable, indeed, were these results that in less than three months about half of the bar was removed by natural scour, without any advance seaward, and an increase of depth of over 4 ft. was secured, and all from a structure not then half com-



ONLY THE PORTION B C WAS COMPLETED. THE REST OF THE BREAKWATER E G IS IN AN UNFINISHED CONDITION, YET THE BAR HAS BEEN ABOUT HALF REMOVED WITHOUT ADVANCING SEAWARD. THE SUBMERGED GOVERNMENT JETTY PREVENTS FURTHER DEEPENING OVER ITS CREST, WHERE ROCK IS FOUND AT 13 FT.

FIG. 4.

Mr. Haupt.

Mr. Haupt. pleted. Such a result is unprecedented in the annals of harbor-bar removal by natural agencies.

It may excite curiosity, therefore, to discover wherein lies the truth of the statements contained in the next paragraph, as follows:

"When the jetty was completed it was found that there was less water in the channel than before the work began. Colonel Goodyear, the last contractor, recognized the mistake that had been made, and proceeded to finish the jetty on the south side of the Pass, thus excluding the drift sand brought in by the currents and waves from the south, with the gratifying result that the author's latest survey, made in June, 1897,* showed a marked increase in the depth of the channel. Further evidence is unnecessary to establish the fact that, at this point, at least, the littoral currents flow from the south."

This would seem to point out the danger of generalizing from special cases, for, while the sand does drift at certain periods of the year, to a limited extent, from the south, its resultant direction is from the opposite quarter. As to the correction of "the mistake" by the completion of the south jetty by Colonel Goodyear, there is no room for great differences of opinion. If this south jetty was completed, it was not platted on the surveys and was never reported to the consulting engineers, who were merely advised that some sand-bag revetments were placed on the south bar to temporarily concentrate the ebb currents on the real cause of the difficulty, viz., the old Government jetty covered with rock, and the curved portion of which was reported to have "practically disappeared" seven years before this work was located, but which, unfortunately for the people of Texas, was discovered to be in place lying directly across the channel at depths varying from "8 to 14 ft.," and which no current could remove. It was found to act as an effectual retaining wall and barrier to the acquisition of the requisite depths, and the plan has been officially condemned because the 15 ft. predicted for this half-finished portion was not secured, but without recognition of the fact that this obstruction, placed in the channel by former engineers and reported to have disappeared, still remains in place and is the cause of the failure to secure 15 ft. by scour.

As already remarked, the jetty was never completed and the outer end of the channel is unprotected (see Figs. 4 and 5), so that the bar formation at and beyond this old jetty is not under the control of the currents, and consequently this portion of the bar remains with but very little material to be removed, and with variable depths. The present low-water depth is 11 ft., covering only a ship's length, while there are holes extending to 15 ft. on both sides of the obstructing jetty.

If the author made a survey in June, 1897, and found "gratifying results," he must have been cognizant of the fact that prior to that

*On the Company's chart of June, 1897, Fig. 5, no such jetty is shown.

date the contractor had exploded some 23 000 lbs. of dynamite on the old government jetty, in his effort to remove it, and that, in consequence of the partial breach made, the inner contours advanced seaward and remained permanently in this new position; but, as the contour maps show only a space of about 300 ft. in width over this jetty, having depths of "13 ft. and rock," it was not sufficient to permit the currents to do their work effectively; yet the author attributes the benefit solely to the sand bags placed near the old south (Nelson) jetty. Is this a full diagnosis of this problem, and is the conclusion justifiable? It seems remarkable, first, that, in the recent reviews of this incomplete work, no stress has been laid upon the existence of the old

Mr. Haupt.

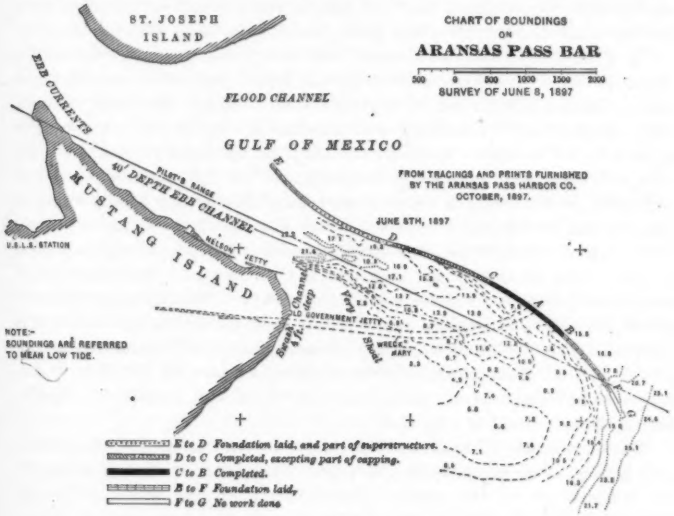


FIG. 5.

"Mansfield" rock jetty sunk directly across the channel and reported to have disappeared, yet which has proven to be the main cause of the interruption to the excellent results which the first part of the breakwater was producing; second, that the jetty is regarded as "completed," which is far from the fact; third, that the depths after such alleged completion were found to be less than before the work began, and fourth, that after the alleged completion of the "south" jetty by Colonel Goodyear (which was never built in the sense indicated, and which is not shown on the survey of "June, 1897," or any other), it should have produced such "gratifying results," and to show such a marked increase in the depth of the channel as to require

Mr. Haupt. no further evidence to establish the author's premises. The inventor of this system invites discussion, but desires that it be fair, open and honest, and that due weight be given to all the factors *pro* and *con*, in order that the relative value of this method of improving ocean bars may be fully revealed. If far greater results can be secured by one jetty than by two, it merits a fair test, which it has not yet secured. Aransas Pass is an admittedly difficult location, yet it is claimed that this partially built breakwater has produced, at that point, incomparably greater results than those secured by the government, at one third the cost and in one-twentieth the time. Ten years have elapsed since it was first made public, and the various respectful and courteous requests, made of the parties having jurisdiction over harbor works, to permit a test to be made, have been silently ignored.

It so happened that at Aransas Pass the private parties who held a franchise from the Government, having failed to secure results from other devices, concluded to try this plan, but for financial reasons they determined to handicap it at the start by cutting it in twain, and agreed to build only "1 250 ft. of complete breakwater and 2 600 ft. of apron extension," covering the portion *F B C D* upon a predicted result of 15 ft. Such a result would undoubtedly have been secured but for the fortuitous circumstance of the old jetty lying at about 13 ft. below the surface, and covered with rock which was reported to have been scoured bare, and which the Company and contractor neglected to remove, for reasons of their own. This much of history seems necessary to explain some of the misrepresentations as to the results of this design and to show its remarkable utility and economy as a method of improving harbor entrances, and in developing the commercial resources of the country, in which the profession should take a deep interest at this time.

The experience at Aransas Pass points to the belief that the resultant littoral drift is, therefore, not from the south on this portion of the Texas coast, as the author states, but from the north. This is sufficiently indicated by the prevailing directions of movement characterizing the inlets along this portion of the Gulf littoral.

Mr. Pitts. THOMAS D. PITTS, Jun. Am. Soc. C. E.—As the author refers to the results of the work at Aransas Pass, as evidence in favor of his theory, it seems proper that the speaker, who was for two years assistant engineer on that work, should make some statement as to the conditions and results there, especially as he is informed that the late chief engineer, Wm. Dunbar Jenkins, M. Am. Soc. C. E., will be unable to contribute to the discussion.

The speaker does not desire to discuss the author's general theory, as he is not sufficiently familiar with the subject, and that theory has already been so ably discussed by others, but he would like to say that the author seems to base his theory largely on the prevalence over

the Gulf, for nine months of the year, of a strong southeasterly wind; and that, while this wind does prevail at points on the coast where records have been kept for a term of years, as at Corpus Christi and Galveston, the pilot charts of the United States Hydrographic Office show the average yearly wind resultant as being about east by south in the western half of the Gulf and nearly east in the eastern half. Mr. Pitts.

On page 97 the author refers to the jetty at Aransas Pass as being completed, but to this statement exception must be taken.

The jetty is now only half completed, and the portion yet unfinished is a most vital part of the work, since its completion would fully control the tidal volume, only a part of which is now utilized to produce scour.

It does not seem quite fair to conclude, because a half completed work fails to do what the whole work was expected to accomplish, either that the work is a failure or that the theories and observations on which the plans were based were erroneous.

When work on the jetty at Aransas Pass was begun in July, 1895, the entrance was closed by a crescent-shaped bar, with channel depths varying from 9 or 9½ ft. in winter to 8½ ft. or less in summer. The line of the proposed jetty crossed the crest of the bar near the point *A* (Fig. 5), and the axis of the channel in use at that time about midway between the points *C* and *D*. The depth in the channel was about 9 ft., and the least depth on the axis of the present channel about 8 or 8½ ft.

The consulting engineers had predicted that the completion of the portion *B C* of the jetty, and the laying of the foundation 3 ft. high above the bottom from *C* to *D*, and from *B* to *F*, would give a navigable depth of 15 ft., it being understood that the jetty must be completed at once in order to hold this depth. It was known that the Government had laid the foundation of a south jetty, about 10 years before, which, if still in existence, would form a dam across the proposed channel, but it was believed* that this foundation had entirely disappeared.

At first the results were very gratifying, and depths of 13 ft. and greater were obtained in a few months, together with a very marked reduction in the width of the bar, but it soon developed that the old Government jetty had not disappeared, and that the 13-ft. channel passed through a low spot or break in this jetty, the average depth over the rock of the old jetty being from 9 to 12 ft., from the wreck of the *Mary* to the outer end. Of course, rock having been reached, it was physically impossible for the current to scour a deeper channel.

On March 1st, 1896, the condition of the jetty was as follows (see Fig. 5): A foundation 1 000 ft. long and 3 ft. high above the bottom was laid from *F* to *B*, the depth of water over the rock being from 8 to 13 ft.; from *B* to *C*, 1 250 ft., the jetty was fully completed; from *C*

* On the authority of the Report of the Chief of Engineers, U. S. Army, for 1888.

Mr. Pitts. to *D*, 1 500 ft., the foundation was laid, and a riprap mound had been built thereon to the level of mean low tide, and had then been allowed to wash down and take its natural slope under wave action, the depth of water over the rock being from 4 to 6 ft.; and a foundation 3 ft. high had been laid for a distance of 1 400 ft. from *D* toward *E*. At this time there was little or no current across the bar, the ebb flow passing out between *C* and St. Joseph Island, and most of it at and just west of *D*. About this time, too, was the beginning of the season of southeasterly winds in that year, and they blew almost without a stop during the months of March, April, May and part of June. No one who has lived on that part of the Texas coast can doubt that during the prevalence of these southeast winds there is a large sand movement along shore to the northward and eastward. It would be hard to devise a better trap to catch this sand and cause it to be deposited on the bar than the jetty in its unfinished condition, and the depth on the bar did, in fact, at once begin to decrease.

Work was carried on, when the weather permitted, during the four months mentioned, but was suspended, for want of funds, from the latter part of June until the first of August. At the time it stopped, in June, the portion *C D* had been built to the water surface and partly capped, but the greater part of the ebb flow and the strongest currents still passed out between *D* and St. Joseph Island.

After much urging, the Company provided a limited amount of money, with which work was resumed early in August. By the end of September, when the funds were again exhausted, the foundation had been extended to *E*, and a narrow ridge of rip-rap had been built to the level of mean low tide between *D* and *E*, except in two places, one about 400 ft. long, near the middle of *D E*, and one about 100 ft. long at a distance of 600 ft. east of *E*, where gaps were left, the money on hand not being sufficient to close them. The depth of water over the rock in the smaller gap is about 6 or 7 ft., and in the larger one 5 or 6 ft., and the current through them approaches $4\frac{1}{2}$ miles per hour during ebb-tide. No work has been done on the jetty since September, 1896, and it is to-day in substantially the condition described above.

On October 1st, 1896, the depth on the bar was not more than $6\frac{1}{2}$ ft., and during October and November it decreased to 6 ft. As stated above, when work was resumed in August, there was but a feeble current across the bar, but as soon as the portion *D E* was partially completed to low-tide level, as described, it increased to a surface velocity of 3 ft. per second and more.

About the first of December, work was begun under the contract with Colonel Goodyear, and was actively prosecuted until May. During this time 23 500 lbs. of dynamite were exploded in the channel, and the "south jetty," mentioned by the author, was built. This latter

was composed of sand bags with a little rock protection on the channel side. It did not at any time extend more than 300 ft. from shore, and has since been washed away. The speaker believes that this jetty had no appreciable effect upon the depth of water on the bar. The dynamite, however, had a good effect, especially by breaking up and partially removing about 300 ft. of the old Government jetty. Mr. Pitts.

In February, 1897, the depth on the bar was $7\frac{3}{4}$ ft., and in June it had increased to $8\frac{3}{4}$ ft. In November last the depth on the bar was a little over 9 ft., and when the speaker left Aransas Pass in March it was 10 or $10\frac{1}{2}$ ft. He is informed that it has continued to increase since that time, and that the depth on the bar is now 11 ft., notwithstanding the southeast winds and northerly currents of the past spring.

A part of the increase between December, 1896, and June, 1897, was doubtless due to the use of the dynamite, but the speaker does not think that all, or even the greater part, of it came from that cause, for there was every reason to expect an increase in depth during the winter, which is the season of strongest ebbs; and, besides, the depth has continued to increase slowly since the use of the dynamite ceased, thus showing the good effect of the breach in the old Government jetty and the partial completion of *C D E*.

The speaker wishes to emphasize the fact that before the portion *D E* of the jetty was partially built up to low-water level, the currents were not controlled, and did not cross the bar with any strength, and that it was before that section was built up as described that the shoaling, cited by the author in support of his theory, took place.

Since June, 1897, a shoal has been noticed lying to the south of the channel, the shape and position of which are shown by the contours on the map. During the past fall and winter this shoal has been dry at extreme low tide for a distance of 1 000 ft. or more from shore, except for a narrow and shallow channel close to the beach, and it was possible to wade out to the wreck of the *Mary*, where in July, 1895, there were depths of 12 to 15 ft. This shoaling seems to be due chiefly to an eddy which is formed to the southward of the channel during ebb-tide, and which causes the sediment in a portion of the ebb waters to be deposited, as well as part of that carried by the littoral current. The eddy seems more marked when the littoral current is flowing to the southward than when it flows in the opposite direction, but in either case sand is deposited on this shoal. There has also been a marked shoaling to the north of the jetty, covering a greater area, but of less depth. This result was expected to follow the building of the jetty, and indicates a littoral current from the north, because there is no eddy here to account for the shoal as there is on the south side of the channel.

In conclusion, it seems hardly correct to call this work a failure, when, in spite of delays and partial completion, it has radically

Mr. Pitts. changed the location of the channel and fixed it in position, has caused an increase in depth of 5 ft. or more from the worst condition of the bar, which condition itself was caused by failure to properly push the work, as urged by the engineers; has given an available depth of 2 ft. more than could be found when the work began, and has caused the large advances of the inner deep-water contours. All this was accomplished when only half of the total amount of material required had been put in place, and without causing any advance seaward of the deep-water contours on the outer face of the bar. The crest of the bar is now a little outside of *B*, and the speaker believes that this would soon disappear if the section *B F* were completed and the old Government jetty entirely removed.

Instead of considering this work a failure, the speaker thinks that it has not yet had a fair trial, and that the results have been remarkable, in view of all the unfavorable conditions. He believes that a depth of 15 ft. would have been obtained during the winter of 1895–96, as predicted by the consulting engineers, but for the fact that the foundation of the old Government jetty lay directly across the channel, at a depth of about 11 ft., and prevented the current from cutting deeper. No provision was made by the Harbor Company for the removal of this foundation, although they were repeatedly urged to do so by the engineers.

It is quite likely that a spur jetty on the south side of the channel would have been found desirable to keep out the sand-laden northerly current during the spring and summer months, and so prevent fluctuations in the channel depth; but there is no doubt that the jetty, as originally designed, would have secured the depths it was planned to secure, had it been pushed to completion in a reasonable time, provided the old Government jetty foundation had been removed as soon as it was discovered.

The jetty at Aransas Pass as yet gives no conclusive evidence regarding the direction of the littoral currents on this part of the Texas coast, but after two years' observation and study, the speaker believes that the yearly resultant of the littoral drift is south and not north. This seems to have been the cause of the former decided southerly movement of the Pass. There is, however, at certain seasons, a strong, persistent, sand-bearing current, flowing north along the shore, which must be taken into account in designing harbor works on this part of the Gulf coast.

Mr. Cameron. BREWSTER CAMERON, Esq.—The speaker does not presume to discuss this subject from a professional standpoint, but merely wishes to state the results of his observations as a practical man. A map of Aransas Pass and the bays opening into it, made by a Mexican engineer about one hundred years ago, when Texas was a part of Mexico, shows that the pass or entrance to Aransas Harbor was then at a

point opposite Lydia Ann Islands, or about 1½ miles northerly or easterly from the present location. This map, together with the official surveys of the United States Government covering a long period of years, conclusively shows that the Pass has steadily worked its way southwesterly. This has doubtless been caused by the heavy northerly winds that prevail during the winter season. These winds drive the waters of the bays with great force in a southwesterly direction, causing a continual erosion of the south side of the Pass and a constant cutting away of the islands which are situated on the southerly side of all passes along the Texas coast. The same winds that produce these heavy currents in the bays, and which lead to this great scour, produce equally strong currents in the Gulf near the shore, and these currents carry a great amount of sand southwesterly along the Texas coast, producing a heavy littoral drift which builds up the islands on the north side of the Pass, as the heavy currents in the bay cut away the islands on the south side of the Pass, thereby maintaining the normal width of the channels to all the harbor entrances. Mr. Cameron.

These physical facts demonstrate conclusively the basic error in the paper, viz., that the drift is from the south or west. A casual investigation of the conditions that exist at Aransas Pass is very likely to be misleading. There is a light prevailing wind from the south or west during the summer, which causes a slight movement of the sand toward the north or east. It is so noticeable near the surface that it is likely to deceive a casual observer, but it is so insignificant, as compared to the drift from the north, that it is a grave error to make the statement that the resultant drift at this port is from the south. The movement of the islands in a southerly or westerly direction shows conclusively that this is not a fact.

As to the conditions that exist on the coast of Texas, the speaker's conclusions coincide entirely with the opinions expressed by Messrs. Ripley, Wisner, Haupt and Pitts. In connection with the harbors of Texas all these gentlemen have had extensive personal experience, and particularly Major Ripley, to whose exhaustive experiments, carried on through a long period of years, the people are indebted for the results published in the official reports by the United States Government. These reports have incontrovertibly established the fact that the resultant drift is from the north.

Referring particularly to the conditions existing at Aransas Pass, fortunately actual experiments have been made which amount to a mathematical demonstration of the fact that the resultant drift is from the north or east. The fact may be cited that the Mansfield jetty, which was constructed, as at Galveston, on the south side of the Pass, extended the bar seaward as the jetty was being constructed, and produced no additional depths over the bar; whereas a spur jetty only 600 ft. long, constructed by the late Colonel George W. Fulton, on the

Mr. Cameron.

north side of the Pass, secured an increased depth of 2 ft. over the bar, as shown by the reports of the Corps of Engineers, U. S. A., and without extending the bar gulfward. Against demonstrated facts of this character, the mere expression of opinion by anyone should have no weight whatever. It is unfortunate that the author has fallen into these errors, as it is most important to the entire West that the favorable conditions existing at Aransas Pass should be correctly understood, and it is greatly to be regretted that he has misunderstood the whole theory of the harbor improvement contemplated by the construction of the reaction breakwater. So far from being a failure and not realizing the expectations of those who designed it, the speaker personally knows this to be erroneous. Messrs. Haupt and Ripley were employed by him to prepare the designs for the improvement of Aransas Pass, and the work, so far as constructed, has far surpassed the expectation of the speaker and the predictions of the engineers, having scoured out so great a quantity that the distance between the outer and inner 20-ft. contours has been reduced nearly half a mile. The scouring force of the current produced by the reaction breakwater, which was only partially completed, has not only accomplished this, but has rapidly deepened the bar until the work of erosion was stopped by the old Government jetty, which lies directly across the channel at a depth of from 11 to 13 ft. The sand covering this obstruction was scoured down to the bare rock, which the currents could not remove and the contractor did not, since it was not included in his contract.

Instead of being a mistake, as stated by the author, the work has been designed, located and executed with consummate skill, and every anticipation of the engineers has been realized as to intercepting the drift, regulating the currents, fixing the location of the channel and inducing rapid scour by this reaction breakwater, with the single exception of securing the predicted depth of 15 ft. to result from this incompleted work. As already stated, it failed solely because of the obstructing Government jetty, which had been officially reported as having long since disappeared. Certainly, if there is anyone to blame for failure it would seem to be the United States engineers for not correctly reporting the facts as to the existence of the old jetty, and for taking advantage of this neglect to remove the obstruction erected by them, to condemn the reaction breakwater.

The speaker believes that nowhere else in the world have such great results been secured in so short a time and at such moderate cost, and that by this method of treating ocean bars the profession of civil engineering had made a distinct advance.

CORRESPONDENCE.

GEORGE Y. WISNER, M. Am. Soc. C. E.—The author has apparently based his conclusions, as to the direction of the littoral currents along the Texas coast, on the fact that, at most of the harbor entrances, the south jetties have generally been constructed first, and that such jetties were for the purpose of shutting out sand from that direction. When it is considered that such construction has resulted in the waste of millions of dollars, and in some cases has caused a deterioration of the channels which the works were designed to improve, it may be well to examine more closely into the facts of the case. Mr. Wisner.

From the Rio Grande to the mouth of the Mississippi River there is not a single harbor entrance, where the formation is such as to show the effect of littoral currents, that does not furnish conclusive evidence that the resultant direction of currents is from the northeast.

It is true, as stated in the paper, that these shore currents are greatly influenced by the force and direction of the prevailing winds, but, from a careful examination of the weather records for that section, it will be found that, while the wind is generally from the south during the summer months, the force is so small that the currents to the northeast seldom extend much below the surface; whereas the winds from the northeast, east and southeast, during the autumn, winter and spring months produce currents of from 2 to 3 miles per hour, and to a great degree are the controlling factors causing sand movement along the coast.

At the mouth of the Mississippi River the sediment transported through the jetties is entirely carried to the westward of the entrance, causing a shoal half a mile outside of the end of the west jetty.

Previous to the improvement of South Pass, the movement of the bar seaward was 100 ft. per year, but for the past eighteen years the littoral current across the entrance to the jetty channel has prevented any advance, or the formation of any bar in front.

At the mouth of the Brazos River, Texas, the phenomenon of sediment deposit is exactly similar to that at South Pass. The Brazos is one of the heaviest sediment-bearing streams on the Gulf Coast; and, while the outer face of the bar was pushed seaward 3 000 ft. by deposits from the river during the construction of the jetties, the littoral currents completely eroded and carried away to the westward this entire deposit within a year after the works were completed to the crest of the bar.

The statement as to the unusual agitation of the waters of the Gulf, 40 miles southeast of Aransas Pass, will need to be substantiated be-

Mr. Wisner.

fore being accepted as the source of the Gulf currents through the Straits of Florida.

The direction of the resultant littoral current along the Texas coast has been established beyond question by careful observers, whose conclusions are entirely in accord with those which should be arrived at from a study of the form and movement of the natural harbor entrances on that coast.

The works at the entrance of Aransas Pass were not based on any "supposition" as to the direction of the littoral current at that place, but on known conditions; and the results already obtained from the incomplete breakwater indicate that, when completed, and the old jetty across the channel is removed, the required depth to the harbor entrance will be obtained and easily maintained.

It is well known that the flow across the outer end of the breakwater will cause an eddy to the westward of the works, which will carry sand into the channel, unless the south jetty be carried far enough seaward to prevent such action. The plans for the Aransas Pass work contemplated such construction, and, so far as the writer knows, no change has been made in this regard since the work was started.

At Galveston the action of the eddy to the west of the jetties has been sufficient to erode the shore along the city front to a considerable extent.

The utility of a single jetty for producing deep and safe entrances at harbors on sandy coasts depends largely on the direction of the littoral resultant along the coast, and the length of spur jetty needed on the lee side of the entrance will vary with almost every location.

At Aransas Pass the spur on the south side of the channel will have to be carried out some 2 000 ft. from shore to prevent the inflow of sand.

The River and Harbor Bill for 1896 appropriated $2 345 000 for the improvement of the entrance to Cumberland Sound, Ga., by means of parallel jetties. At this place the movement of sand is from north to south, and, if a properly located north jetty be constructed first, the required depth of channel would be obtained, and more than $1 000 000, required under present plans for building the useless south jetty, would be saved.

Mr. Wrotnowski.

A. F. WROTNOWSKI, M. Am. Soc. C. E.—This interesting subject cannot be too lightly handled, and the data for its study should be of the most authentic class in order to give it a sound basis for a proper consideration. The author, perhaps, is in a measure correct as to the general trend of the flow of the littoral currents along the Texas coast, but these currents are so varied in their direction at other points as to defy the assertion that their trends are in positive and well-defined directions. The writer has measured currents at depths of

5 ft., 10 ft., 15 ft., 20 ft. and 25 ft. in the Gulf, opposite and about two miles off the ends of the jetties, on various occasions during their construction, and in a number of instances the surface, 5-ft. and 10-ft. floats, went southward, while those of greater depths went northward against the surface current, and, generally, the middle-depth floats were undecided in their movements. On these occasions there were slight winds from the north which caused the surface current to run southward. At various other times the writer has also noticed ships anchored in the offing and heading north during a stiff southerly breeze. This, however, can be accounted for by the fact that for a few days previous the wind had been strong from the north, thus setting the current southward. The indications are that the shore or littoral currents are mainly governed by prevailing winds, and do not, as a general rule, form a material factor in determining the location for jetty works. Mr. Wrotnowski.

The author is misinformed about the South Jetty at Tampico having been built before the North Jetty. In fact, the latter was out about 1 500 ft. before the former was commenced. However, his views upon the greater accumulation of sand deposit next to a south jetty seem to be reinforced, as, in the case at Tampico, there is now much more sand south of the South Jetty than is the case north of the North Jetty. This difference, however, is due in a great measure to the fact that during northers the water accumulates and is driven against the North Jetty, and finds its way out, in an increased current, licking the North Jetty with such energy as to scour the sand from that side and sweep it past the front of the jetties to the south side.

ALEXANDER E. KASTL, M. Am. Soc. C. E.—During the four years, 1888 to 1891, inclusive, the writer was connected with the Brazos River Harbor Improvement, in Texas, as Principal Assistant Engineer and Engineer, and with the Tampico Harbor Improvement, in Mexico, as First Assistant Engineer. His observations were that the resultant direction of the littoral currents on the Gulf coast is southwestward at the mouth of the Brazos, and southward at Tampico. These currents are sand-bearing. At the mouth of the Brazos the northeastward currents produced by southwesterly winds are mere surface currents and have no appreciable effect on the sand movement. The same is true of the northward currents at Tampico. A study of the detail charts of the Brazos River and Tampico Harbors will show that the sand movement is southward. Mr. Kastl.

In reference to the jetties at Tampico the north jetty was started first, and, later on, the south jetty. Both jetties were carried seaward together. The original intention was to begin work on both jetties at the same time, but, as the railroad facilities were all on the north side of the river, earlier and greater progress was made on the north jetty.

Mr. Kastl. The writer was at Tampico Harbor when the work was started, and during his stay there, until April, 1891, the work on the north jetty was always in advance of that on the south jetty. The plan of improvement did not contemplate the building of either jetty first, but the building of both jetties at the same time, seaward, as fast as possible, and this plan was followed as nearly as it could be. Tampico Harbor is the mouth of the Panuco River, and the improvement accomplished the removal of the bar at the mouth of the river. Before the jetties were built the depth of the channel over the bar was not more than 10 ft., whereas now there is a channel of about 25 ft.

Much information in regard to the littoral currents along the Texas coast at the mouth of the Brazos River is contained in a paper,* entitled "The Brazos Harbor Improvement," by George Y. Wisner, M. Am. Soc. C. E.

Mr. Raymond. THOMAS L. RAYMOND, M. Am. Soc. C. E.—The importance of the author's conclusions in defining the limits and direction of the littoral currents of the Gulf of Mexico, can scarcely be overestimated in their practical bearing upon the methods and ultimate efficiency of the work of harbor improvement on the coast of Louisiana, Texas and Mexico. From the Mississippi River to Tampico there are only two harbors to-day which will admit vessels of greater draft than 12 ft. over the bars, though there are many which are of ample capacity inside the sand-bars blocking the entrances.

The improvement of some of these harbors, in addition to those now under treatment, is certainly the work of the near future, and any testimony corroborative of the record of facts cited by the author must prove of value in deciding upon the economical location of the controlling structures at any given place.

At Sabine Pass, to which the author refers casually, the limited appropriations for starting the work enforced the construction of only a portion of one jetty under the first contract, and it was decided to build the west jetty foundation first, on the theory that the littoral current, which was well understood to flow westward, would meet the outward current from the harbor and produce a stronger eroding stream in the direction of the resultant and parallel to the line of the jetty.

Sabine Pass is 60 miles east of Galveston and unlike most, if not all, other harbors upon the Gulf of Mexico, had not a suspicion of sand upon its bar, and only a narrow fringe of sand on its western bank.

There was much surprise when it was discovered after the foundation of the west jetty had been built, that a sand bank had formed against it covering the work completely in places, and extending, with diminishing thickness, 3 000 ft. to the eastward.†

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* *Transactions*, Vol. XXV, 1891.

† See report to Capt. Turtle, in Report of Chief of Engineers for 1885.

So improbable did it appear that this deposit had come from the littoral current, when so little sand was found in the vicinity, that its formation was attributed to the scour from the harbor above and sediment from tributary streams. Mr. Raymond.

In the light, however, of the author's investigations of the experience gained and increased depths produced by the construction of the east jetty, it seems certain that this sand was caught by the obstruction presented by the west jetty to its westward flow along the shore. The fact that this deposit was found only upon the outer slope of the bar in depths from 6½ ft. to 9 ft. beyond the line of the Gulf shore, where the bottom had formerly been a soft clay, easily penetrated by a prod to the depth of 30 ft., adds to the probability of the conclusion that this sand was brought from the eastward by a littoral current of considerable velocity.

Had the east jetty been built first, it is fair to presume that this drift would have been excluded from the channel, and that the increase in depths would have been realized, in some degree at least, before the construction of another jetty.

Another phenomenon observable at all the mouths of the Mississippi River, at Calcasieu Pass, and, in a marked degree, at Sabine Pass, is the projection of the western banks of these harbors, further into the Gulf than the eastern shore line. At the entrance to the South Pass jetties, for instance, the shoaling beyond the end of the west jetty has built up to within 7 ft. of the surface for 1 000 ft. seaward of the terminus of the works, while the widest and deepest channel has for 16 years turned sharply to the eastward around the end of the east jetty, directly in the teeth of the undoubted westerly littoral current.

At Sabine Pass, where the outflow is practically free from sediment, the sand deposit is found only on the west bank near the entrance. This seems to indicate that the westerly drift, previously described as caught by the foundation course of the west jetty, which was built first, meeting the outward current from the harbor, is carried by the resultant current into the influence of the eddy west of the entrance and thrown up on the west shore.

The tendency is, therefore, to build out the western shoals toward the channel in a direction opposed to the set of the littoral current. When the obstruction of the west jetty foundation caught this sand drift, this effect was produced in a marked degree in one year, and the line of deepest water moved a considerable distance to the eastward.

H. C. Ripley, M. Am. Soc. C. E.—The author has opened up a subject of the greatest interest to engineers devoted to the study of problems involving the effects of ocean currents, and, while he has apparently given the subject much study as regards its literary Mr. Ripley.

Mr. Ripley.

aspect, he seems to have fallen into serious error as to the local conditions on the Texas and Mexican coasts.

The writer is familiar with these conditions at all the important harbors on the Texas and Mexican coasts from Sabine Pass, Texas, to the Coatzacoalcos River, Mexico, having made personal examinations, more or less extensive, at the following places, viz.: Sabine Pass, Galveston Harbor, Brazos River, Brazos Santiago, Tampico, Vera Cruz and the mouth of the Coatzacoalcos River, and his study of the subject extends over a period of more than twenty-five years. It is the purpose of the writer to limit his discussion to those conditions of which he has personal knowledge.

It is undoubtedly true that there are times when the littoral current along the coast of Texas flows to the north and east; but it is equally true that at times it flows in the opposite direction. The writer has observed this phenomenon many times and at many places along this coast. Under his direction a series of observations, extending from 1880 to 1884, were made on Galveston Bar at such times as work was being done on the south jetty, to determine the direction and force of these currents. The result showed that the southwesterly currents largely prevail during the fall and winter months, while the northeasterly currents prevail during the spring and summer months. It has also been observed that when the wind is easterly or northerly the littoral current flows southwesterly, and when the wind is westerly or southerly the current is in the opposite direction. This has led to the conclusion that the littoral current along this coast is to a large extent, if not entirely, dependent upon the wind. The coast of Texas from Sabine Pass to Aransas Pass, is nearly straight, and has a general direction of southwest by west. The line normal to this direction is southeast by south and northwest by north. Winds from either of these directions will be directly on or off shore, and hence their effect in producing littoral currents will be *nil* unless it be considered that the water banked up by on-shore winds must find a lateral escape along the shore in either direction from some central point; and similarly the depression caused by off-shore winds may cause a tendency toward the restoration of the equilibrium by lateral shore currents. Winds blowing from directions from N. W. by N. around to the N. and E. to S. W. by S. will tend to produce a southwesterly littoral current, while winds from directions from N. W. by N. around to the W. and S. to S. W. by S. will produce a northeasterly littoral current.

In the report of the Chief of Engineers, U. S. A., for 1880, page 1 220 *et seq.*, there are thirteen diagrams which show the direction of the wind, the number of miles traveled and the duration in hours for each month in the year from June, 1879, to May, 1880, inclusive, and for the whole year, made from the records of a self-registering

anemometer at Galveston, Texas. The latter diagram (for the whole year) is reproduced in Fig. 6, and to it is added a dotted line through the center of the compass rose indicating the neutral axis of wind effect upon littoral movement. The direction of this line is N. W. by N. and S. W. by S. The full line shows the number of miles traveled by the wind, and the dotted line the corresponding time. The scale for the wind is in miles, and for the time is in hours, the circum- Mr. Ripley.

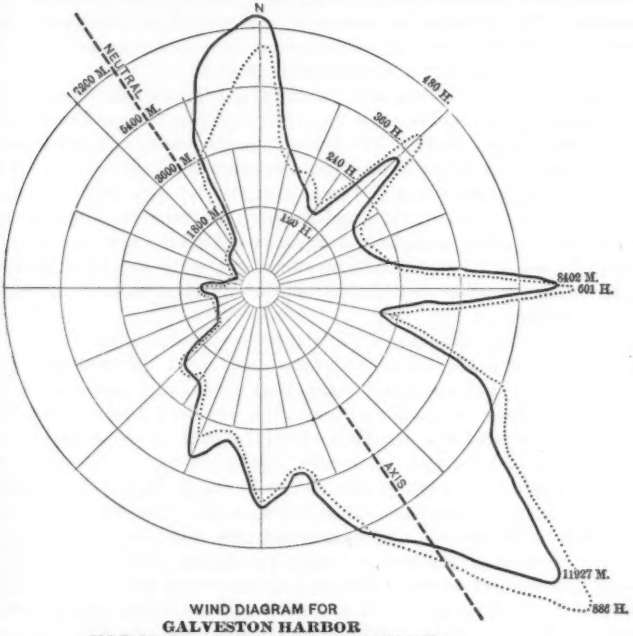

FIG. 6.

ference of the small circle at the center of the compass rose being the zero of the scale. The area embraced within the curve to the right of the neutral axis (looking N. W.) represents the amount of wind tending to produce a southwesterly littoral current, while the area embraced within the curve to the left of the line represents the amount of wind tending to produce a northeasterly littoral current. It may be seen from these diagrams that winds favorable to the production of a south-

Mr. Ripley. westerly littoral current prevail almost wholly throughout the months of September, October and November, the greater part of the months of January, February, March, May, June and December, a small part of April, and somewhat more than half of the months of May and August; while the winds favorable to the production of a northeasterly littoral current prevail during nearly the whole of the month of July, the larger part of April, a considerable part of August, and only a very small part of January, February, March, May, June and December. The diagram for the whole year (Fig. 6) indicates that more than two-thirds of the winds throughout the year are favorable to the production of a southwesterly littoral current.

However, this is not all. The littoral movement, that is, the movement of sand along the shore, is dependent upon other conditions than simply that of the current. A current may flow gently in one direction for a long time without producing any appreciable effect in sand movement, unless the sand is stirred up and held in suspension by wave action, and it is well known that those winds which tend to produce a southwesterly current also produce the heaviest breakers upon the coast; hence the littoral movement to the southwest is much greater than is represented by the duration of the littoral current in that direction.

The resultant amount of the littoral movement along the northwest and west coast of the Gulf of Mexico is more definitely shown by the character of the bars and channels at the various passes along the coast. In their original condition the channels leading from the passes across the bar to the Gulf were invariably flexed to the south, with two notable exceptions, namely, the mouth of the Brazos River, in Texas, and the mouth of the Panuco River, in Mexico. The cause of the southerly flexure at other places is the resultant southwesterly littoral movement, which deposits sand upon the northeast side of the channel and forces it over to the south. This was very evident at Galveston where the channel after passing beyond the gorge, turned abruptly to the south and extended for 4 miles before crossing the bar. At Pass Cavallo the channel hugs the west shore of the Pass for more than 4 miles to the south, when by going southeast a much shorter route to the Gulf could be had. At Aransas Pass the channel formerly turned south inside of the wreck *Mary*, crossing the bar far to the south of its present position. The easterly flexure of the channel at the mouth of the Brazos River is caused by the alluvial deposit from the river, to the west of the mouth, due to the southwesterly littoral current. This deposit, being at times greatly in excess of the littoral movement of sand, forces the channel to the eastward on the line of least resistance. A similar condition exists at the mouth of the Panuco River, in Mexico, where the enormous alluvial deposit in front and to the south of the mouth of the jetties has caused

a northeasterly flexure of the channel, to meet the conditions of least resistance. Mr. Ripley.

The southwesterly movement of the passes along the Texas coast is also a measure of the resultant littoral movement. Galveston Island has very materially shortened its length at the east end by erosion and increased its length at the west end by accretion, within the period of official surveys. Pass Cavallo has moved to the westward within the experience of the writer, so as to completely engulf an old fort built by the Confederates, and has eroded the shore for considerable distance beyond.

The movement of Aransas Pass is remarkable. The following table, compiled from official records, shows the amount by periods:

MOVEMENT OF ARANSAS PASS TO THE SOUTHWEST FROM 1861 TO 1887.

Dates.	Movement.	Time.	Movement per year.
1861 to 1868	1 300 ft.	7 years.	186 ft.
1868 to 1871	650 "	3 "	217 "
1871 to 1875	400 "	4 "	100 "
1875 to 1878	1 500 "	3 "	500 "
1878 to 1882	700 "	4 "	178 "
1882 to 1885	150 "	3 "	50 "
1885 to 1887	75 "	2 "	37 "
1861 to 1887	4 775 ft.	26 years.	184 ft.

An inspection of this table shows that the southwesterly movement of this pass, although not uniform, has been continuous for 26 years, and the topography of St. Joseph Island indicates that this movement has progressed, from a point near Lydia Ann Island, a distance of $2\frac{1}{2}$ miles from its present location probably within the present century. The extraordinary movement from 1875 to 1878 was probably due to the storm of 1875, which was one of remarkable severity, and the small movement since 1882 has been due to artificial works which, since their completion, have rendered the position of the Pass stable.

The theory advanced by the author as a basis for the design of the curved breakwater partially constructed by the Aransas Pass Harbor Company is entirely new to the writer, and if it were correct the designers of the work would certainly be subjected to the ridicule of the profession. A concise statement of the theory upon which this work was designed is to be found on page 33 of House Document 137, 55th Congress, 2d Session, from which the following quotation is made:

"In plan it will differ from the usual form of jetty or breakwater, being detached from the shore and located on the bar to the 'wind-

Mr. Ripley.

ward' of the channel. Its axis will be curved (compound and reverse) to produce reactions similar to those found in the concavities of streams, and having radii sufficient to maintain channels of the requisite depths, as revealed by existing curves and their resulting depths of over 30 ft., now found inside the bar. It is designed to fulfill the fundamental conditions of (*a*) arresting the littoral drift; (*b*) admitting the full tidal prism to the interior lagoons; (*c*) controlling the ebb currents and producing a reaction across the bar; (*d*) changing the condition of equilibrium of flood and ebb currents in favor of the latter; and (*e*) of affording aids to navigation by a structure of only half the length of the usual convergent or parallel jetties in pairs."

The partial execution of this work has fully confirmed the correctness of this theory, both as to results and economy of execution.

If the author has really proved, as he says, by a series of experiments that the littoral current at Pass Cavallo comes from the south, it would be a valuable addition to his paper to include that demonstration in his final remarks.

Mr. Sweitzer.

N. B. SWEITZER, Jr., Jun. Am. Soc. C. E.—It was not the intention of the author to enter into the merits of the different systems of jetty construction, nor did he intend to cast any reflections on Mr. Cameron, and his engineers, Messrs. Haupt, Wisner and Ripley, as to the merits of their reaction jetty at Aransas Pass, Texas. That the jetty was well planned and the idea novel, there can be but little doubt, and if it had been placed on the south side of the Pass instead of the north, with the spur jetty north of it, in the opinion of the author, the promised depth would have been obtained. In this connection it should be stated that the last Government survey of the Pass, in the fall of 1888 (of the instrumental work of which the author was in charge), showed no positive evidence of a "jetty crossing the work" and stopping erosion on the crest of the bar.

The author, on behalf of the contractor, and Mr. Pitts for the company, had joint charge of a survey made about four months previous to this, which revealed nothing positive as to this old jetty. There is a supposition, but no positive proof, that this jetty still exists.

Considerable stress is put on the fact that the inlets on this part of the Texas coast are moving toward the south, and, therefore, the littoral current also must necessarily move south.

"It is generally assumed that the motion of a body is in the direction of the resultant of the component forces acting upon it. This being a physical law the direction of movement of the inlets (when unrestricted) should indicate the direction of the forces causing that effect. Hence, when it is found that an inlet is moving to the south, it is difficult to understand how the littoral current (producing that progression) flows from the south."

The littoral current moving north along Mustang Island (Fig. 7) intersects the current either at ebb or flood tide coming through the Pass and normal to it, thus changing the direction of the littoral current

ERRATUM.

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Page 122, twenty-eighth line: For 1888 read 1897.

(locally) and preventing it from impinging on the south side of St. Joseph Island. The littoral current does not have, at all times, of itself, enough bottom velocity (as mentioned in the paper) to carry the heavy sands, but, held in suspension by the waves, they are carried across the Pass from Mustang Island, from which they are detached by continuous and heavy breakers caused by southeast winds, and deposited on the south shore of St. Joseph Island. It should be mentioned here that winds from the north, or "northers," do not cause surf, and hence the sands are but little disturbed on the Gulf side, but these winds do drive the waters with great velocity out of the bays, thus helping in the southward movement of the inlets. As northers last but a few days in winter, they are but a small factor. The rip-rap placed on the northern shore of Mustang Island has stopped the erosion of that shore line, but in six months, including the summer of 1888, when there was not one day of north winds, St. Joseph Island moved south 200 ft., narrowing the Pass to that extent. These are facts, not theories, as the author has watched this movement for three years. Mr. Sweitzer.

The prevailing winds in this locality, not Galveston or Florida, are from the southeast, and blow from that quarter for nine months in the year, as records kept at Corpus Christi show. Hardly a day passes in the summer months when the wind does not blow at the rate of from 15 to 30 miles an hour. It might be proper to state here that this is with one exception the windiest place in the United States, especially in the summer.

FIG. 7.

Mr. Haupt's theory regarding the circulation in the Gulf is very interesting, but when it is remembered that after entering the Gulf the rate of speed is about 3 miles an hour and it would be hard to see how this could be kept up for hundreds of miles without exerting a propelling force, it is probably here that the "vertical movement" mentioned comes in.

Mr. Ripley's wind diagram for the harbor of Galveston, coincides exactly with the author's theory, viz., that the littoral current comes from the east in the vicinity of Galveston, where it meets that from the southeast depending on the intensity and velocity of the wind. It should be understood that this current is controlled by the wind, and, like the Gulf Stream proper, is subject to many fluctuations, but that the main course is that indicated by the author.

Mr. Kastl is respectfully referred to the Annual Report of the Chief of Engineers, U. S. A., September 6th, 1887, which states:

"A map of recent survey shows the channel, instead of running southeast in the direction intended, turned off at a right angle and running northeast across the jetty."

Mr. Sweitzer.

The author was misinformed regarding the jetty at Tampico, but if the south jetty was not built first, it should have been.

Mr. Wisner observes that: "The direction of the resultant littoral current along the Texas coast has been established beyond question by careful observers." The author has a letter from Professor Mendenhall, Chief of the Coast Survey, in which he says: "Nothing positive is known of the currents in the Gulf of Mexico."